THE EFFECT OF AMBIENT
AND BODY TEMPERATURES UPON REACTION TIME

Report No. 151-1-13
Project No. 20-M-1b
15 March 1948

Report prepared by:

Division of Bio-Mechanics
The Psychological Corporation, New York

John D. Coakley, Acting Director

George Forlano
G. Forlano, Ph. D.

Work authorized by:

Contract N6-ori-151
Task Order No. 1
Designation No. NR-783-004

Ltr dtd 6 Feb. 1947, Ser. No. 3831 SD from the Office of Naval Research, Navy Department
Sands Point, Port Washington, Long Island, New York

Joseph E. Barmack
J. E. Barmack, Ph. D.
Assistant Project Director

John D. Coakley
J. D. Coakley, Ph. D.
Project Director

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I. Orientation

As airplanes are designed for higher speeds, it is generally recognized that they will operate at altitudes above those commonly encountered either in commercial or military aviation. Measurements and estimates of the upper atmosphere indicate that low temperatures prevail at some altitudes and, at others, the temperature may be very high (3).

Accordingly, both the high and the low limiting temperatures which man can tolerate are appropriate topics for a discussion of the human limitations to be encountered in the operation of high speed aircraft. These limiting temperatures may be called temperature tolerances and, obviously, such tolerances must be defined in terms of some satisfactory criterion. In the case of high temperatures, the criterion might be the bare avoidance of collapse due to heat (3). Another criterion which has been employed is the reported comfort of persons placed in a given thermal environment (3). Thus, there can be as many temperature tolerances as there are identifiable criteria. One criterion, which has not been used extensively but which has great practical significance, is the onset of performance deterioration. This criterion sets the question, what are the thermal conditions under which human performance is significantly impaired? The literature shows that some performances deteriorate under milder conditions than those at which other performances begin to reveal impairment. Thus, there can be many performance tolerances for temperature.

In this report, reaction time studies have been singled out for examination because, of all the kinds of performance which have been studied, the task of depressing a key at a given signal is in several respects the simplest. Furthermore,

this performance is unique among those tasks which have been studied in that it is the most resistant to adverse effects from extreme temperatures. Evidence for these statements appears in a classified report of this series.

The review of the literature is organized about three main topics:

(1) Effects of low ambient temperatures on reaction time.

(2) Effects of high ambient temperatures on reaction time.

(3) Relationship between body temperature and reaction time.

II. Summary and Conclusions

1. Studies of reaction time have been reported for temperatures from -50 degrees to +117 degrees F. The following conclusions apply to simple discrimination and to choice reaction times within the range of conditions examined. The conclusions should not be applied to speed of other performances.

(a) Reaction time does not vary significantly with low ambient temperatures provided the body generally and the responding member in particular are properly protected.

(b) During exposures for several days to temperatures as low as -20 degrees F, clothing can adequately protect the body without interfering significantly with the speed of the simple reaction.

(c) For periods of about an hour, current-type clothing affords adequate protection against ambient temperatures as low as -50 degrees F.

(d) Conditions which may reduce strength and dexterity of movement may leave reaction time unchanged.

(e) Reaction time does not vary significantly with high ambient temperatures up to +117 degrees F provided the wet bulb temperature does not exceed about 86 degrees F.

2. Some evidence indicates that reaction time varies inversely with body temperature over a restricted range of body temperatures. (The study of Hollingworth (6) can be regarded as contrary evidence.) Possibly, when conditions are such that ambient temperature alters body temperature, changes in reaction time may be expected. This inference, however, has not yet received direct experimental support.

3. The practical importance of the above conclusions is that, if it should be necessary or desirable to expose the pilot of high speed aircraft to extreme temperatures, he will be able to perform with practically normal speed provided his activities can be restricted to the kind of performance involved in the reaction time experiment. The duplication of the essential attributes of this performance requires that the pilot be forewarned and prepared for each response, and that the manipulation be restricted to simple, all-or-none controls such as readily accessible keys and switches.

III. The Effects of Low Ambient Temperatures upon Reaction Time

There are two reports and five pertinent experimental studies to be cited. None, however, contains a systematic exploration of the relation between temperature and reaction time. Despite this lack of systematic treatment, some inferences of practical importance can be drawn from the data. The salient facts of each experimental study have been arranged in Table IV on page 15.

1. Armstrong and Heim (1) report that, in spite of the protection afforded by winter flying clothing, aviators begin to suffer the effects of cold at about +14 degrees F. The hands and feet are the first parts affected. Muscular movements become increasingly sluggish until tissue destruction and death ensue at -40 degrees to -58 degrees F. Since this is a report based on interviews with pilots, quantitative data are not provided.

2. Fulton (5), in discussing the effects of reduced temperature on the body during flight, states that exposure to cold for sufficient duration to cause a drop in rectal temperature slows motor performance and decreases cerebral activity to such an extent that operational efficiency is greatly impaired. No quantitative data or pertinent references are presented.

3. Horvath and Freedman (7) investigated the effects of exposure to a temperature of -20 degrees F and zero wind velocity on several psychomotor performances, including visual discrimination reaction time. Prior to the exposure, 22 male subjects were exercised outdoors for 12 days and were then brought into an air-conditioned laboratory maintained at a temperature of 72 degrees F and relative humidity of 50 percent.

After four days in this environment, they entered a cold room maintained at a temperature of -20 degrees F and remained there continuously for a period of 8 to 14 days. Each morning, after arising from their sleeping bags, their daily routine in the cold chamber consisted of the following: psychomotor tests, breakfast, a one-hour walk at 2.5 mph, sitting quietly for two hours, and then lunch. After lunch, there was an hour for walking also at 2.5 mph, one-half hour of work, another hour of walking, psychomotor tests, and then supper. Partial escape from the cold was possible by the provision of a small hut in the cold chamber, the temperature of which ranged between 0 and 32 degrees F. The men usually returned early in the evening to their sleeping bags. These men wore a six-piece Arctic assembly with mukluks and felt boots (Alcan type) and the M-1943 head-mitten combination.

The reaction time test entailed 50 responses of the subject to one of two neon tubes. Tests were administered at the beginning, in the middle, and at the end of the day's work. No significant changes in average time for response were noted when the men were placed in the cold room. The investigators concluded that exposure to cold of the order of -20 degrees F for about 14 days has no influence on the speed or precision of the reaction to visual stimuli as measured by this test. However, on the basis of the other tests, such as Gear Assembly, Hand Grip, and Johnson Code Test, they concluded that the dexterity of the fingers and hand strength were diminished by exposure to low ambient temperatures, even when the duration of such exposure was for a <u>relatively short</u> period of time (3 hours).

This study demonstrates that reaction time for a simple visual discrimination is not significantly altered by exposures to -20 degrees F for periods of several days if proper clothing is provided. Nevertheless,

under these same conditions strength and dexterity are reduced.

4. The problem of tolerance to cold under differing dietary conditions has been examined by Keeton, Lambert, Glickman, Mitchell, Last, and Fahnestock (9). Some of their results are relevant to a study of the relationship between reaction time and temperature since one of the tests employed was a reaction time test administered when the subjects were placed in a "comfortable" (72 to 77 degrees F, relative humidity 35 $\pm$ 5 percent) and then in a "cold" (-21 to -19 degrees F) room.

The 12 subjects in this study were healthy men, 23 to 25 years of age, who volunteered to participate in the experiment. When these men were placed in the "cold" room, they were provided with clothing appropriate for military operation in the Arctic zone*. The tests were carried out in four series arranged within an eight hour period each day for five experimental days. The reaction time test involved a discrimination reaction in which a key was manually depressed for a green but not for a red stimulus light. The measures are reported to have stabilized during a preliminary training period in the "comfortable" room. Table I shows the increase in time due to exposure to cold for periods of eight hours. The differences in performance, based on the initial and final tests during each exposure, are expressed in the table as coefficients of comparison. Evaluation of these data will be postponed until a closely related experiment is described in the following paragraph.

* The clothing worn in this experiment consisted of (1) 90% cotton and 10% wool union suit (Vassar), (2) 50% wool two-piece union suit (Arctic G.I.), (3) 100% wool ribbed socks, (4) 100% wool knee length socks (Arctic G.I.), (5) cotton poplin jersey-lined trousers (Arctic G.I.), (6) 100% wool pullover sweater (Arctic G.I.), (7) 100% wool scarf (Arctic G.I.), (8) 100% wool helmet (Arctic G.I.), (9) 100% wool mitten inserts (two pairs) (Arctic G.I.), (10) cotton poplin mitten shells (Arctic G.I.), (11) fleece inner-liner (Arctic G.I.), (12) cotton poplin hooded parka (Arctic G.I.), (13) fleece-lined Naval flying boots, and (14) 100% wool wristlets.

TABLE I

Increments in discrimination reaction time after exposure to cold (-20°F) for eight hours

Each increment, expressed as a coefficient of comparison, is the average for five consecutive exposure days. (After Keeton et al. (9))

High Protein Diet		High Carbohydrate Diet	
Subject	Choice Reaction Time	Subject	Choice Reaction Time
A	0.25	D	-0.13
B	0.19	E	0.51
C	0.54	F	0.35
G	0.22	J	0.10
H	0.45	K	0.54
I	0.41	L	0.45
Aver.	0.343	Aver.	0.303
Decrement in performance	11%	Decrement in performance	10%

5. Shortly after the completion of the foregoing experiment, Mitchell, Glickman, Lambert, Keeton, and Fahnestock (13) employed nine of the same subjects and one additional man in a similar study of tolerance to cold using a high carbohydrate versus a high fat diet. Present interest in this study does not rest in the effects of diet claimed by the authors but rather in the reaction times measured during exposure for eight hours to a temperature of -20 degrees F. During the exposures the subjects wore heavy Arctic clothing*. The figures shown in Table II are coefficients of comparison similar to those shown in Table I.

A brief glance at Table I strongly suggests that a reliable effect of temperature has been demonstrated. Since the authors state that there is not a significant difference in reaction time between the two dietary groups (P = 0.38), all of the 12 increments can be considered together. Accordingly, 11 of the measures show an increase in time after exposure to cold. In Table II all ten subjects show an average increase in time. (The P-value for the difference between the dietary groups in Table II is 0.32). However, before accepting these results at face value they must be examined somewhat more critically. The value of 0.25 shown for subject A in Table I means that A's reaction time increased during exposure to cold by one-fourth of one S.D. unit. The standard deviation is given as 3.145 without indication of the unit of time. Evidently the increments shown in Table I are, on the average, just about equal to the unit of measurement (3.145 x 0.343 = 1.1). Such small increments raise a question about the reliability and the practi-

* The clothing worn in this experiment consisted of the assembly listed in the footnote on page 6 except for items (11) and (12). A cotton poplin, wool-lined field-jacket (Arctic G.I.) was added.

TABLE II

Increments in discrimination reaction time after exposure to cold (-20°F) for eight hours

Each increment, expressed as a coefficient of comparison, represents the average from 13 consecutive daily tests except for an intervening weekend. (After Mitchell et al. (13))

High Carbohydrate Diet		High Fat Diet	
Subject	Choice Reaction Time	Subject	Choice Reaction Time
A	0.64	D	0.13
B	0.13	E	0.51
C	0.83	F	0.48
G	0.45	L	0.89
H	0.99	M	0.38
Aver.	0.608	Aver.	0.478
Decrement in performance	20%	Decrement in performance	16%

cal importance of the results. If the unit of measurement were 1/1000 sec, a standard deviation of about three milliseconds would be far too small as judged by comparable experiments. On the other hand, a unit of 1/10 sec would yield a standard deviation too large. Probably, then, the unit was 1/100 sec. If so, the alleged temperature effect is only 10 milliseconds.

The decrements in performance shown in the tables also require elucidation. The underlying thought of these investigators is that performance varies from average (mean of the comparison population) to poor (3 S.D.'s above the mean). The group of subjects placed on a protein diet fell 11 percent of the S.D. distance above the mean, i.e., 0.343 S.D. above the mean as indicated by the average increment in time. As already shown, this is presumably of the order of 10 milliseconds and an increase of this magnitude would represent a three to four percent increase in time. Such performance decrements as given in these tables can be very misleading unless the method by which they are derived is kept clearly in view.

The statistical reliability of this difference, which is presumably of the order of 10 ms, is not given in either of these studies but it can be computed from the data provided. If each time increment is multiplied by 3.143, the original differences in time are recovered and these can be evaluated by means of the usual formulas for evaluating the significance of differences. The computed t-value is 5.50 for Table I and 5.79 for Table II. The corresponding P-values are both less than one percent, which means that for both studies the average difference is reliably greater than zero.

This statistical test, however, does not prove that the lowered temperature caused the lengthening of reaction time. Diurnal variation in reaction time might be the cause. Hollingworth (See Figure 1 on page 26) in 1914 showed a diurnal trend in visual choice reaction times amounting to roughly

two milliseconds per hour. For a period of about 8 hours, this could account for a difference of more than ten milliseconds. Since a similar curve for subjects working at night has not been determined, the trend for those subjects cannot be suggested. As will be shown in a later section, some investigators have not observed precisely this trend. Nevertheless, the fact that such a trend is known to occur under some conditions, and the fact that testing some of the subjects at night may not counterbalance the trend, leaves diurnal variation, as it has been called, a possible explanation for the bias in measures.

From the foregoing analysis it is clear that both of the dietary studies have demonstrated significant, although very small, increases in reaction time but these changes cannot be ascribed with certainty to lowered ambient temperature.

6. Williams and Kitching (16) studied the effects of exposure to zero degrees F and to -50 degrees F on simple auditory and on simple and choice visual reaction times. The subjects wearing regulation flying clothing, valued at 2.8 Clo*, while in the cold room were required to respond to flashes of light from a 6-volt bulb and to clicks from a loud speaker in the simple reaction time tests. Multiple reaction time was studied by requiring the subjects to press the appropriate response key for red, yellow, and blue lights. The results for five subjects at zero degrees F were negative. In fact there was no significant difference in mean reaction time between either of the experimental temperature conditions and the control. The only evidence of slower reactions was a mean difference between the ten slowest reactions

* 1 Clo is the unit of clothing insulation required to maintain in comfort a sitting, resting subject when the temperature is 70 degrees F and the air movement is 10 feet per minute.

under experimental as compared with control conditions. This difference was attributed to the extreme discomfort produced by exposure to severe cold.

7. Craik and Macpherson (2) have reported a few observations of the effects of cold upon hand movement and reaction time. In contrast to the other studies which have been examined, this experiment involves direct cooling of the hand making the response. Two subjects immersed their hands to the wrists for 15 minutes in an ice and water mixture having a temperature of 44.6 degrees F. Records of reaction time to light were taken with a Morse key and with triggers differing in required pull measured in pounds. Results for each of the subjects are shown in Table III. No indication is given of the number of observations involved or of the reliability of the measurements.

These observations suggest that cooling of the responding extremity may increase reaction time for a light load, e.g., a ten percent increase in reaction time using the Morse key, and a 13 to 14 percent increase using a trigger of 20 to 30 lb load. There was a complete failure, however, to operate a trigger requiring a pull of 46 to 62 lb, although under normal conditions this trigger could be pulled in about 0.45 sec. It is interesting to notice that, even in these sketchy results, strength failed before there was a serious lengthening of reaction time for either of the two observers.

Summary

Results of the studies of the effect of low temperatures upon reaction time are summarized in Table IV. The studies reviewed in this section indicate that:

1. Pilots wearing winter flying clothes begin to suffer from low temperatures at +14 degrees F. At about -40 degrees F sluggish muscular movements and severe symptoms begin to appear.

2. When the extremities are properly protected, simple and choice

TABLE III

Reaction times for two subjects before and after immersing their hands in ice water (44.6°F) for 15 minutes. (After Craik and Macpherson (2))

Response Required	Subjects	Reaction Time		
		Before exposure	After exposure	Increase due to cold
Depress Morse Key	1 Female	0.19 sec	0.21 sec	10%
Pull Trigger 20 lb	1 Female	.21	.24	14
30 lb	1 Male	.21	.27	29
46 lb	1 Female	.46	failure	--
62 lb	1 Male	.47	failure	--

reaction times are insignificantly affected by low temperatures. Even exposure to temperatures as low as -50 degrees F for approximately one hour are without appreciable effect. In two companion studies dealing with dietary problems a small but statistically significant lengthening of reaction time was found after men were placed in an ambient temperature of -20 degrees F. However, the conditions were such that this difference could not be certainly ascribed to the lowered temperature.

3. Local cooling of the responding hand may increase reaction time to some extent (approximately 10 to 15 percent).

TABLE IV

Summary of effects of low ambient temperatures upon reaction time.

I. Experiments with lowered ambient temperature

Temp. °F.	Effect	Subjects	Duration of exposure	Clothing	Investigator
0	No decrease in simple auditory and simple and choice visual reaction time	5 men		2.8 Clo	Williams and Kitching
-20	No change in visual reaction time. Diminished strength and dexterity of hands	22 men	8 to 14 days	Arctic assembly	Horvath and Freedman
-20	Small, significant increase in reaction time not necessarily due to temperature	12 men	8 hours	Arctic Clothing	Keeton et al.
-20	Small, significant increase in reaction time not necessarily due to temperature	10 men	8 hours	Arctic Clothing	Mitchell et al.
-50	No change in simple auditory and simple and choice visual reaction time	5 men	1 hour or less	2.8 Clo	Williams and Kitching
II. Experiments with local cooling of responding hand					
+45	10% increase with Morse key 13% increase with load of 20 to 30 lbs failure with load of 46 to 62 lbs	1 male 1 female	15 min		Craik and Macpherson

IV. The Effect of High Temperature and Variations of Humidity on Reaction Time

A rather careful search of the literature discloses that very few data have been reported for reaction time in high ambient temperatures. Very possibly there are relevant data scattered and hidden in a number of studies dealing with other topics, thereby escaping the dragnet of bibliographic aids. Attention is called to this situation to elicit comment and to suggest a by-product of some interest which might issue from current or prospective researches. However, there are many unsolved problems, both in the field of reaction time and in the field of temperature tolerance, which are presumably much more deserving of research effort than the problem just posed.

Two relevant studies are examined to round out the picture of reaction time and ambient temperature.

1. In a study of the effect of hot living quarters upon men working in high ambient temperatures, Pace, White, Fisher, and Birren (14) included a discrimination reaction time test. Twenty volunteer hospital apprentices were allocated to an experimental and a control group and subjected to the temperatures shown in the following schema:

Group	N	Working environment			Non-working and test environment		
		Hrs	Dry Bulb	Wet Bulb	Hrs	Dry Bulb	Wet Bulb
Control	10	7	108°F	83°F	17	85°F	71°F
Exper.	10	7	108°	83°	17	95°	83°

The work for each of the ten successive days of the experiment consisted of walking at 4.5 mph on a power-driven treadmill for eight periods of five minutes each, spaced within the daily work period. As shown in the schema, the essential dif-

ference in the treatment of the two groups was in the temperature prevailing at the time the tests were administered (non-working environment). Average times are shown in Table V. The means obtained on the first day of the experiment indicate that the men placed in the higher temperature surroundings responded slightly faster than the men in the cooler room (0.278 versus 0.284 sec). The difference is not statistically reliable. Of course, it would not be possible to interpret such a difference even if it were reliable because there is no evidence that the groups were matched for speed of reaction. The two sets of means which are taken from the fifth and tenth days of the experiment indicate an unreliable difference in the opposite direction. Thus, there is no evidence that an ambient temperature of 95 degrees, as compared with 85 degrees, has a significant effect upon the length of discrimination reaction time. The generality of this interpretation is qualified by the fact that both

TABLE V

Mean discrimination reaction times for two groups of ten men each. The ambient temperature differed for the two groups. Means from the first, fifth, and the tenth day of the experiment are shown. (After Pace (14))

Means for first day (sec)			Means for fifth day (sec)			Means for tenth day (sec)		
Hot environment	Cool environment	P%	Hot environment	Cool environment	P%	Hot environment	Cool environment	P%
.278	.284	70+	.230	.216	30+	.214	.202	40+

groups of men were exposed to a temperature of 106 degrees F for seven hours each day. Although no significant changes in reaction time were found, other tests revealed detrimental effects of the higher temperature upon performance. Pace (15)

acknowledges that this experiment suffered from several limitations. The duration of the exposure to heat was short in comparison with military conditions, and it was unlikely that acclimatization had been completed in ten days. Furthermore, it was not possible to duplicate exactly the diet, technics of measurement, and other variables in the test routine. Accordingly, the following study was performed to obtain additional information.

2. Pace et al. (15) exposed two groups of six men each to a "hot" environment of 90 degrees F dry bulb and 83 degrees F wet bulb for nine hours daily. Three hours a day were spent performing treadmill work tests in a "very hot" environment of 108 degrees F dry bulb and 83 degrees F wet bulb. The experimental group remained in the "hot" environment for 12 hours at night while the control group was removed to a "cool" environment of 80 degrees F dry bulb and 70 degrees F wet bulb. These conditions continued for 30 days. Both groups lived in a "cool" environment for eight days preceding and six days following the experiment. Physiological and psychological tests were conducted throughout the entire period of 44 days, but a report will be made here only of the findings on reaction time. It is important to remember, however, that both groups performed their tests in the heat and that the essential difference between them is continuous or intermittent exposure to heat.

There were three tests on which reaction time was measured:

(a) Reaction time, auditory: The subject released a key as quickly as possible when he heard a 120-cycle tone. A warning light preceded the sound stimulus by an interval that varied between two and six seconds. There were 40 trials at each test session. The same number of trials and type of warning signal were used on the two other reaction time tests.

(b) Reaction time, complex visual: The subject was required to react differentially to an odd or even number of lights presented out of a maximum of nine. Response was a right or left hand key release.

(c) Reaction time, two-choice visual: The subject was required to react with a right or left hand key response to a right or left hand neon light stimulus.

The daily measures of the two groups were compared by means of Fisher's *t*-test. Analysis was not made of differences based on an over-all comparison of the two groups for 30 days because of the opinion that a small difference which was not significant on any single day was not important from the viewpoint of personnel efficiency.

These day by day comparisons of the mean group scores show no significant difference on any day during the experiment on the auditory reaction time test. On the two other reaction time tests, the mean score of the experimental group was consistently superior to that of the control group. This difference was statistically significant (P = 5 percent) on the complex visual reaction time on the twentieth experimental day and thereafter; and on the two-choice reaction time, in 6 of the 36 comparisons during the experimental and recovery periods. These facts might suggest that persons exposed continuously to the heat might show an occasional superiority in performance.

Such a conclusion is unwarranted, however, because the experimental and control groups were not equated for speed of reaction time at the start of the experiment. The slight original superiority of the experimental group may have become a statistically significant superiority because continued practice tends to reduce the variability of performance. Unless proper controls are introduced, the superiority ascribed as an effect of heat may, in fact, be a statistical artifact. Pace's own conclusion is, properly, a cautious one: "None of the sensorimotor functions tested............showed a difference between the two groups."

3. Ivy, Seashore, Van Dusen, Birren, and Harris (8) studied the effect

of benzedrine on the heat tolerance of human subjects exposed to high ambient temperatures. Visual discrimination reaction times were obtained for each of the eight students who served as subjects. For purposes of comparison, control measures of reaction time were made late each morning. After a light lunch, either benzedrine or placebos were administered. Then, after removing most of their clothing, the men entered one of the two hot rooms for a period of six hours during which reaction time was again measured. The experimental design was such that equal numbers of subjects served in both rooms and under drug and placebo conditions. The temperature and humidity specifications for the two experimental rooms follow:

	Dry Bulb	Wet Bulb	Humidity
1. Hot Moist Room	86° F	86° F	100%
2. Hot Dry Room	117° F	85° F	17%

Table VI shows the changes in the time for visual discrimination in the presence and absence of benzedrine and in each of the temperature controlled

TABLE VI

Percent change in visual discrimination time for eight men given placebos or benzedrine and exposed to hot moist or hot dry conditions. The base of the percentages is reaction time measured a few hours prior to each test. (After Ivy et al.(8))

Temperature-Humidity Conditions	Medication Administered: Placebo	Medication Administered: Benzedrine
Hot Moist	+4 ($P>5\%$)	+4 ($P>10\%$)
Hot Dry	−1 ($P>20\%$)	−3 ($P>5\%$)

rooms. When the men were given placebos and placed in the hot moist room, the time was increased by an average of four percent, but the P-value exceeded five percent. Consequently the difference is not reliable statistically. In fact, all four changes fail to reach the five percent level of confidence. The suggestion that the times might be longer under hot moist conditions and shorter under hot dry conditions further indicates the independence of reaction time and dry bulb temperature *per se*. According to the authors, a wet bulb temperature of 86 degrees F was selected because this temperature is near the limits at which the body cooling mechanisms operate adequately.

The effects of high ambient temperatures upon reaction times are summarized in Table VII. Under the conditions of these studies, there is no significant variation of reaction time with ambient temperatures up to + 117 degrees F dry bulb (+85 degrees F wet bulb). These studies show that the temperature range in which reaction time is independent of ambient temperature extends upward to + 117 degrees F provided humidity conditions are properly chosen.

TABLE VII

Summary of effects of high temperatures upon reaction time

Temp Dry Bulb	Temp Wet Bulb	Effect	Subjects	Duration	Remarks	Investigator
86°F	86°F	no significant effect on reaction time with or without benzedrine	8	6 hours	no work during exposure	Ivy
90°F	83°F	no significant effect on one test;	20	21 hours/ day	control group rested 12 hours/ day in cool quarters	Pace
108°F	83°F	apparent decrease in reaction time on two tests held not to be conclusive		3 hours/ day		
117°F	85°F	no significant effect on reaction time with or without benzedrine	8	6 hours	no work during exposure	Ivy

V. The Relationship Between Body Temperature and Reaction Time

In the preceding sections, the conclusion was reached that reaction time is relatively independent of ambient temperature provided the body is protected in specified ways. This conclusion permits the interpretation that the relative independence is contingent upon maintaining constant body temperature. The provision for clothing at one extreme and choice of humidity conditions at the other may serve to supplement the regulating mechanisms of the body in such a way that approximately constant internal temperature is maintained. The question then arises, does reaction time remain constant when conditions are such as to alter body temperature? The study by Craik and Macpherson (2), reviewed earlier, suggests that reaction time may be altered when the local temperature of the responding member is changed. The specific question for this section is whether or not reaction time varies with changes of body temperature as indicated by oral or rectal measurements.

The studies to be reviewed in this section are divided into three groups to emphasize differences in methodology. The three methods which have been used to study this relationship are:

1. To correlate reaction time with time of day and assume that body temperature is also correlated with time of day. This method implies a double correlation with an intervening variable.

2. To obtain simultaneous measures of body temperature and reaction time throughout the day. This method is free from some of the difficulties inherent in the first method.

3. To alter body attitude as a means of inducing temperature changes and relate the temperature changes to changes in reaction time. There are, of course, several ways in which temperature changes might be induced experimentally. Apparently, however, none save changes in body attitude has been employed in studies of reaction time.

Method 1

As indicated above, studies of reaction time as a function of time of

day presume a generalized diurnal temperature curve. Marsh (12), in reviewing research up to 1906 on diurnal variation of body temperature, presents a summarizing graph based mainly on data drawn from French and German sources. This graph reveals a maximum temperature somewhere between 5:00 and 8:00 P.M. and a minimum at about 7:00 A.M. with smooth, gradual transitions between these points.

More recently, Freeman and Hovland (4) reviewed studies on diurnal variation in performance and related physiological processes. They cited studies appearing after 1906 which in a general way substantiate the earlier work in claiming an early morning minimum and a late afternoon maximum. The most recent findings of Duffner and Ross (3) are also in line with prior work. Thus, there appears to be general agreement that body temperature varies through the day and that the variation follows a generalized pattern. However, the precision with which a given subject's curve of variation will be repeated day after day and the congruence of curves plotted for different subjects are not so clear. The references just cited suggest that the pattern may differ markedly from day to day and from subject to subject.

Such data should be considered in evaluating the somewhat equivocal results obtained by Marsh (12), who did not secure temperature measurements to correlate directly with measurements of reaction time. He concluded that reaction times are shorter in the afternoon than in the morning. This would be expected from the temperature curve if reaction time is inversely related to body temperature. However, his results do not indicate a decrease within the period 12:30 to 5:00 P.M. as would be expected from the temperature curve he developed from the literature. In fact, most of his measures show a slight and presumably insignificant increase for this period. This divergence, as Hollingworth pointed out many years ago, could be due to the small number of

subjects and observations.

Hollingworth (6) obtained measurements of visual choice reaction time under normal conditions during a study of the influence of caffeine on simple motor performances. College students and others were asked to respond with the right hand to a red stimulus and with the left to a blue stimulus. Averages based on 10 subjects are shown in Figure 1. Apart from the irregularities of the curve, there appears to be an upward trend from 10:30 A.M. to 8:00 P.M. These results are thus apparently contrary to Marsh's conclusion for at least part of the period under consideration. According to Marsh, reaction times are shorter in the afternoon than in the morning; and according to Hollingworth, they may be longer. Although a variety of differences between the studies could be cited, it would be difficult, if not impossible, to isolate the correct explanation of the discrepancy. Irrespective of the uncertainties about the relation between reaction time and the hour of the day, it is very clear that this method has not given an unequivocal indication of the relation to body temperature. Either the relation of reaction time to body temperature is not clear cut and stable or the diurnal temperature curve is just a highly generalized trend which can not be applied to specific experimental circumstances and subjects with assurance. Studies employing other methods will aid in deciding which of these alternatives is the more acceptable.

Method 2

Kleitman (10) appears to be one of the first investigators to measure body temperature at the time of testing the psychomotor performances of his subjects. He reports that speed and accuracy parallel the trend of the temperature curve for a variety of performances such as dealing cards, transcribing code, multiplication, and mirror drawing.

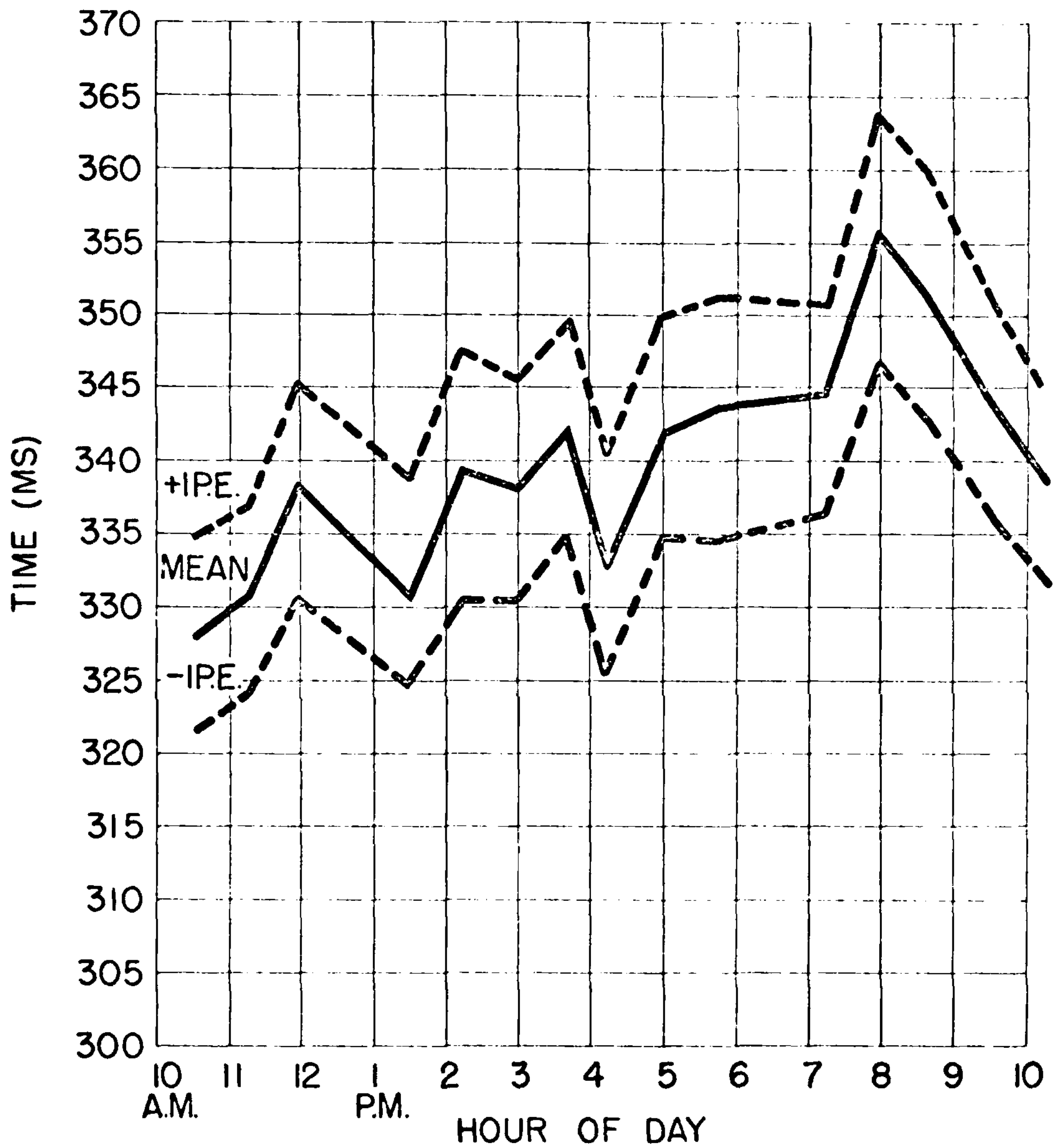

Figure 1. Diurnal variations in visual choice reaction time. Each point on the graph represents the mean response times of ten subjects. The curves for P.E. refer to the probable error of the mean at each plotted point. (After Hollingworth)

Specific attention is drawn to a recent study of Kleitman, Titelbaum, and Felveson (11) in which visual and auditory reaction times were measured concurrently with body temperature for four subjects. Their data are shown in Table VIII. The number of 20-trial periods, indicated by numbers in parentheses following each average reaction time, suggests that the reliabilities of the averages are generally fairly high and therefore the data may be analyzed with confidence. Careful scrutiny of Table VIII will show that there is a tendency for all reaction times to reach a minimum in the early afternoon (1:00 and 3:00 P.M.). However, minima for some subjects and some kinds of reaction may be found at almost any hour of the day. For example, subject 2 has a minimum at 9:00 A.M. for simple visual and subject 4 has a minimum at 6:00 P.M. for simple auditory reaction time. At 11:00 P.M., subject 4 exhibits simple auditory reaction times which are only slightly greater than the mimimum found at 6:00 P.M.

These data support the interpretation that there is a tendency toward systematic variation with the time of day, but that reaction time is subject to the influence of other variables so that this relation does not appear clearly unless the other variables, whatever they may be, are carefully held constant through experimental or statistical controls.

Examination of the measurements of oral temperature will reveal maxima which are prevalent at 3:00 P.M. However, the temperature decreases on either side of the maximum are not parallel for the different subjects. Thus, the diurnal temperature curves for these subjects differ considerably in detail.

The above observations indicate that reaction time and body temperature are each related to some extent to hour of day. The question then arises, are reaction time and body temperature related only by way of their mutual relation

TABLE VIII

Diurnal variation in reaction time in relation to diurnal variation in oral temperature. (After Kleitman et al.)

Average reaction times* in milliseconds

Subject	Hour of day	Oral Temperature	Simple Visual	Simple Auditory	Choice Visual	Choice Auditory
1	9:00 A.M.	97.94	155.2(10)	144.9(10)	258.7(11)	275.6(6)
	11:00 A.M.	98.18	144.6(13)	136.3(13)	248.1(12)	258.5(6)
	1:00 P.M.	98.34	139.9(12)	134.3(12)	236.3(11)	249.2(4)
	3:00 P.M.	98.60	143.3(18)	137.0(18)	234.7(19)	244.2(11)
	5:00 P.M.	98.58	149.6(9)	141.5(9)	236.1(9)	256.5(4)
	7:00 P.M.	98.38	150.4(8)	138.0(8)	238.8(8)	247.7(7)
	9:00 P.M.	97.96	161.6(6)	157.3(6)	254.7(6)	266.0(5)
2	9:00 A.M.	97.81	138.4(5)	135.2(5)	277.0(5)	249.2(4)
	11:00 A.M.	98.10	142.2(17)	134.2(17)	267.5(17)	256.6(11)
	1:00 P.M.	98.05	140.2(16)	130.3(16)	248.6(16)	235.8(10)
	3:00 P.M.	98.23	142.4(24)	139.0(16)	250.1(24)	245.3(11)
	5:00 P.M.	97.84	150.4(8)	136.8(8)	261.0(8)	233.2(5)
	7:00 P.M.	98.15	151.2(5)	139.2(5)	255.8(5)	246.3(3)
	9:00 P.M.	97.60	154.0(2)	149.5(2)	276.0(2)	275.5(2)
3	9:00 A.M.	98.18	184.9(11)	188.0(11)	298.7(11)	238.5(9)
	11:00 A.M.	98.16	183.9(9)	178.1(7)	311.1(7)	296.2(5)
	3:00 P.M.	98.75	181.4(5)	187.4(5)	294.4(5)	286.5(6)
	5:00 P.M.	98.50	186.7(3)	172.7(3)	326.0(3)	271.0(4)
	9:00 P.M.	97.65	190.5(2)	183.5(2)	319.0(2)	
4	7:00 A.M.	97.92	223.0(5)	173.8(23)	378.4(23)	
	9:00 A.M.	98.12	201.2(5)	169.0(22)	365.4(23)	
	11:30 A.M.	98.23		172.7(15)	362.1(14)	
	6:00 P.M.	98.29	188.5(2)	168.3(12)	348.8(12)	
	11:00 P.M.	97.95	203.5(3)	168.4(18)	370.2(18)	

* Figures in parenthesis indicate number of 20-trial periods.

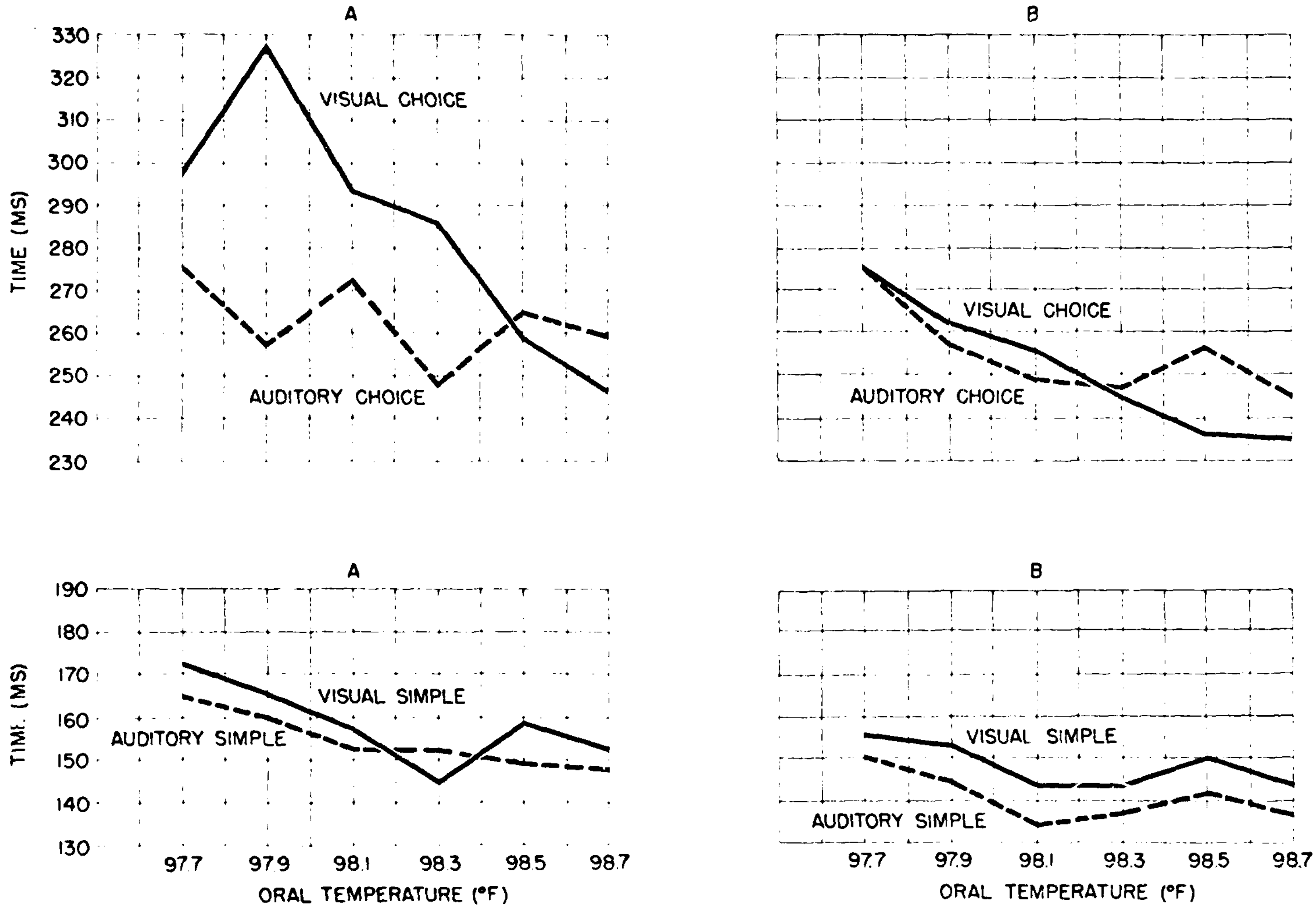

Figure 2. The relationship between oral temperature, on the one hand, and visual and auditory simple and choice reaction times, on the other. Figure 2A is based on the data of all 4 subjects provided in Table VII. Figure 2B is restricted to the data of subjects 1 and 2 provided in the same table.

to time of day, or is there a more direct relation which is not accounted for on the basis of common co-variance?

One simple way to determine whether there is a direct relation is to compute for each subject the rank difference correlations between oral temperature and each kind of reaction. Of course, rho-values based on no more than seven pairs of items are not thoroughly satisfactory and they are, therefore, not presented in tabular form. Nevertheless, it may be mentioned that 14 out of the 15 correlations are negative; several are large enough to be statistically different from zero; and some fall in the region of -1.00.

Figure 2 is a more satisfactory way of indicating the degree of relationship. The curves shown in this figure were derived by setting the temperature measures into intervals and placing them along the X-axis. The pertinent reaction measures were averaged in such a way that each observation received equal weight.

In Figure 2A all four subjects have been included; whereas in Figure 2B data are taken solely from subjects 1 and 2 whose records are complete. The curves for simple visual and auditory reaction time found in the lower part of Figure 2A offer some support for the proposition that time and temperature are inversely related. Positive statements about the corresponding curves of Figure 2B are unwarranted. The co-variation with temperature is somewhat clearer for the choice curves found in the upper part of the figure. Aside from one very pronounced inversion in the auditory choice curve of Figure 2B, the choice curves based on two subjects are rather regular. For a rise in oral temperature of one degree, choice reaction time appears to be shortened by about 10 to 15 percent. Thus, within the range studied, there is some evidence that reaction times and especially choice times are inversely related to body temperature.

Method 3

Kleitman and his collaborators (11) have verified the relationship

between body temperature and reaction time by using the third method outlined previously. They found that if the subject lies down after standing for one hour, oral temperature will fall within one hour. In 14 experiments on 5 subjects, the mean decrement in oral temperature was accompanied by an increment in reaction time. Quantitative results are shown in Table IX. For a mean temperature decrement of .64 degrees F there is not only an increase in choice reaction times but in the simple reactions as well. The size of the increment is about the same for all four kinds of performance.

The authors state that the reverse experiment, in which the subject first reclines and then stands, results in increments in temperature and decrements in reaction time. Data for this latter experiment, however, are not given.

From the studies of Kleitman and his collaborators it may be concluded that, under th nditions so far reported, reaction time and body temperature are inversely correlated, irrespective of whether the changes occur under natural conditions or are induced by changes in posture. This relationship is applicable to the very narrow range of body temperatures studied thus

TABLE IX

Increments in reaction time found after a decrease in oral temperature. (After Kleitman et al. (11))

		Change in Reaction Time			
Statistic	Decrement in Oral Temperature	Simple Visual	Simple Auditory	Choice Visual	Choice Auditory
Mean	-.64°	+30ms	+30ms	+27ms	+30ms
Range	-.45 to -.90°	+6 to +51ms	-7 to+72ms	+9 to +61ms	+1 to +49ms

far.

The studies reviewed in this section suggest that there is a relationship between body temperature and several varieties of reaction time. Changes of a few tenths of a degree in body temperature appear to be associated with measurable changes in reaction time. These facts do not, of course, establish any causal connection between the two variables. One plausible hypothesis is that reaction time will remain independent of ambient temperature provided constant body temperature is maintained and provided there is no serious local cooling of the responding member. Reaction time, however, may be altered when the temperature regulating mechanisms of the body become embarrassed. A direct and systematic experimental test of this hypothesis has apparently not been undertaken.

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